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PULSE POWER CAPACITORS

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Pulse Power Capacitors

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I. ABSTRACT

The US Army Research Laboratory has sponsored a capacitor development program for film dielectric capacitors. The program has evaluated dielectric materials for high energy density capacitors from industrial and academic research programs. High performance capacitors have been developed that meet the needs of today's military applications. The performance of recently developed capacitors will be discussed.

II. PROGRAM OBJECTIVES

The performance objectives for capacitors needed by the US Military is ever changing to meet new applications. The ongoing effort in the development of pulse power capacitors has resulted in remarkable improvements in capacitor performance. These successes have caused a shift in focus to other areas where research is needed.

III. MILLISECOND DISCHARGE CAPACITORS

The performance of the millisecond class capacitors is normally measure in terms of charge discharge cycles. Here the driving requirements have been for Railguns and electro thermo ignition (ETI) guns. The capacitors have been used in these applications for decades. In the case of the Army's requirements to have a large pulse forming network (PFN) on a relatively small vehicle, there is a significant gap between what has been accomplished and what is needed. In terms of the ETI guns, the requirements have been met or exceeded. While a capacitor driven PFN is significantly larger than the designers would like for larger systems, the size of the equipment is steadily shrinking and may meet the requirements of a deployed system in a few years.

The energy density of the capacitors used for railgun PFNs a few years ago it was at 1 Joule/cc. Now, some five years later, there are 2 J/cc capacitors in production for the same application that out perform the 1 J/cc predecessors. The latest version of this capacitor coming out of the laboratory is operating at 2.4 J/cc. This class of capacitor is designed with a high efficiency dielectric. A capacitor starting at room temperature could operate for 200 charge discharge cycles with no cooling and without reaching the capacitors maximum operating temperature and with 200 shots taking place in less than half an hour. Cooling the switches and other parts of the PFN as well as the gun barrel is going to be a far more difficult task.

The weight density of the capacitors will be somewhat determined by the mountings used. For militarized applications, the requirements for the capacitors include operate at an 80 g shock loading. Oil filled capacitors are inherently good at withstanding shocks. The internal parts are soft but surrounded by a dielectric fluid that transmits the force from through the capacitor without damaging the dielectric material. The major concerns are the permanent deformation of the capacitor case and the generation of leaks at the bushings. The bushing stress can be relieved with a light weight flexible connector. The capacitor case is a different matter.

Both the capacitors in Figure 1 are designed to handle 80 g shock loading and the design has been tested for that parameter. The capacitor on the right represents standard construction techniques for capacitors. In the case of the taller capacitor on the left, additional reinforcing was needed in the long dimension to meet the shock loading requirement. Small angles were added to the four long corners. The addition of the steel angles represents a 4% increase in weight for the capacitor.

The comparison in Figure 1 is a practical guide for how large a pulse forming capacitor can be before it will need special reinforcing in order to meet the militaries 80g Shock loading requirement.

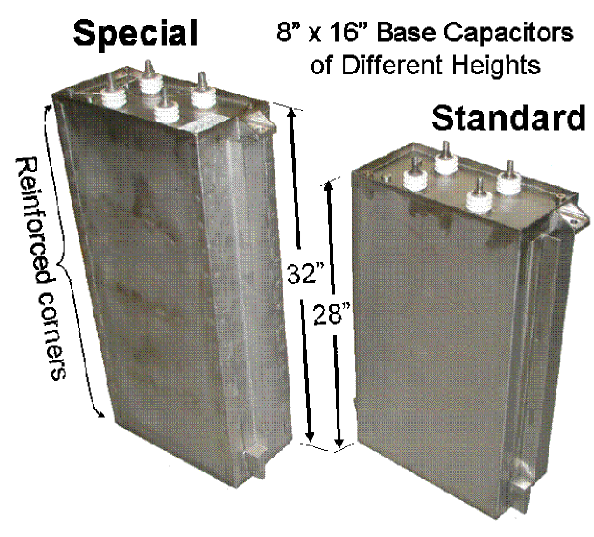

Figure 1 - 80 g Shock Capacitors

Larger capacitors are available for millisecond discharge applications. One capacitor is likely to store over a quarter megajoule. A capacitor operating at 2.4 J/cc and delivering a quarter megajoule will be 50% larger than the capacitor on the left in Figure 1 and will need the special reinforcing. With the extra reinforcing, the capacitors weight density will be about 2.1 J/g

IV. MICROSECOND DISCHARGE CAPACITORS

Work with microsecond capacitors has also yielded significant results. This class of capacitor is used for pulse shaping in millisecond class PFNs when fast turn on or turnoff is required. The higher frequency response millisecond class capacitors are used to form the upper corners of the flat top square wave. For this type of duty, the requirements will determine the actual energy density. Typically the energy density achieved in the faster capacitors is about 80% of slower millisecond discharge capacitors.

In other applications, a long DC life requirement drives the capacitor design. The capacitor must sits fully charged for weeks on end. The life expectancy of this type of capacitor has been improved by a factor of 1000 over the past four years. The shapes of the capacitors vary greatly but generally they have a rectangular cross section.

Microsecond discharge capacitors require a small series inductance budget to perform properly. Larger capacitor requirements often require that multiple capacitors be used to order to meet the inductance budget of the system. Another way of accomplishing this is to use multiple current paths requiring multiple bushings on the capacitors. This has been done microsecond discharge capacitor shown in Figure 2. The same technique is used to minimize the inductance on the capacitors shown in Figure 1.

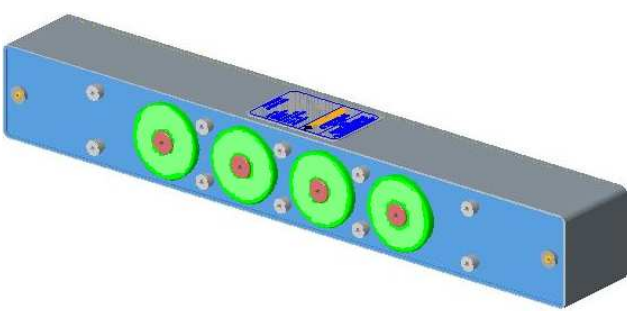

Figure 2 - Typical Microsecond Discharge Capacitor

At present, a 2000 hour DC Life, fast discharge capacitors are available at an energy density of 1.3 J/cc. There are a number of shapes and ratings that have been manufactured and supplied to various military customers.

V. SUB-MICROSECOND CAPACITORS

With the millisecond and microsecond discharge capacitor development successes, the focus of the development effort has shifted. It is now focusing on sub-microsecond capacitors.

Traditionally, capacitors built in this time regime the life expectancy of the capacitors is in the millions or billions of charge discharge cycles. The capacitors are used in accelerators where they operate continuously at repetition rated in the kilohertz range. Because of the duty cycle and long life expectancy, these capacitors operate at very low energy densities. An example of this is the capacitor shown in Figure 3. This capacitor designed to be used in high volumes and is rated for:

- 100kVDC Operating Voltage
- 0.04uF +/-10%
- 0.1J/cc Energy Density
- 50,000 Charge Discharge Cycles
- 90% Survival

The military's requirements for sub-microsecond capacitors are quite different form that of LTD. The capacitors of greatest interest must function for one cycle, or for one burst of cycles, or in some cases for a few hundred cycles. They are designed to fit into specific equipment very restrictive space requirements. Most of the shapes required are round or rectangular cylinders.

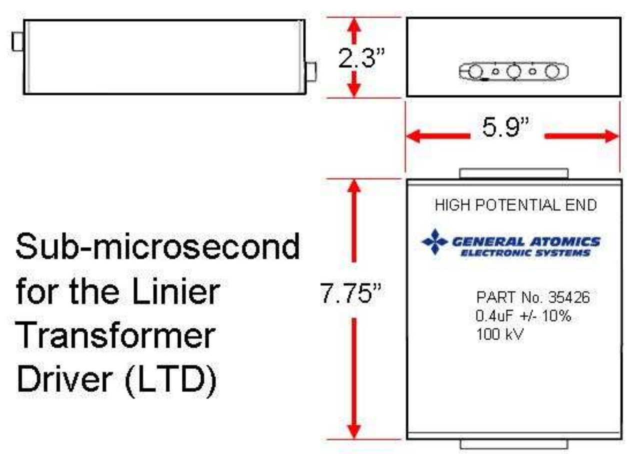

Figure 3 - Conventional Sub-microsecond Capacitor

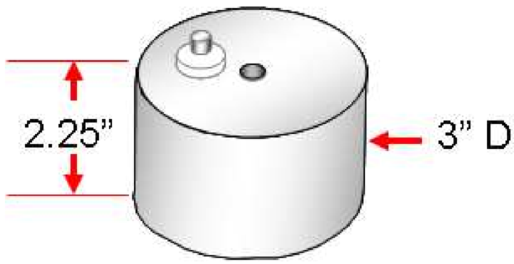

Figure 4 - Sub-microsecond Discharge Capacitor

The techniques that have been used to improve the performance of the millisecond capacitors and microsecond capacitors are now being applied to the sub-microsecond polymer capacitors. The energy density of the capacitors has increased with capacitors shipped by GA-ESI, shown in Figure 4, achieving 2J/cc in a single shot application.

While the energy density of the capacitor in Figure 4 is impressive, it is far from a direct comparison with the LTD capacitor. The capacitor of Figure 4 is designed to operate at a much lower voltage making it simpler to assemble. While this capacitor uses some of the same construction techniques as the millisecond and microsecond energy discharge capacitors, the failure mode is significantly different. End of life for the millisecond and microsecond capacitors is defined as the loss of an arbitrary percentage of its initial capacitance. For the capacitor of Figure 3 at the end of life, 90% of the capacitors in the bank will still be functioning properly. For the capacitor of Figure 4 the capacitor will be an open circuit at the end of life.

VI. PROJECTIONS FOR THE FUTURE

The capacitors described for the most part, represent the state of the art for oil filled pulse power capacitors. Tracking the performance record for oil filled capacitors over the past few years indicates that the pulse power capacitors investigated under the Army program are decreasing in volume by 50% about every 4 years. The continued success of the program has attracted a number of military users who are doing the basic research on capacitors under the ARL program. While there is no guarantee that the rate of improvement will be sustained, the most recent results from testing laboratory capacitors indicate that this trend will carry on in manufactured capacitors for the next few years.

VII. CONCLUSIONS

The present work being done on capacitors for military applications has resulted in significant improvements in capacitor performance in the past few years. The level of effort in capacitor research is expected to continue. This holds promise of better capacitors for use in the energy discharge applications and other areas of interest to the military.

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